A Guide to Remote Sensing:
An overview of the science and its application
to the coastal and marine environment

Developed by

ISLAND INSTITUTE

July 1, 1999

Preface

This guide is intended as an introduction to remote sensing for resource managers, policy makers, and laypeople and was prepared at the request of the Maine State Planning Office. It focuses on instruments that have application to the marine and coastal environments. The guide begins with an introduction to the science and its growing utility for resource management. Next, it outlines the process of implementing remotely-sensed data and describes the core elements of image processing. Several regional applications of remote sensing are summarized in section four, and the guide concludes with an appendix outlining the characteristics of several important instruments.

This document was prepared by Chris Wentzell-Brehme (Island Institute).

The author would like to thank the following for their editorial assistance: Anne Hayden (Resource Services), Cyndy Erickson (Bigelow Laboratory for Ocean Science), Andrew Thomas Ph.D., and Ryan Weatherbee (University of Maine).

Table of Contents

I. Introduction

What is Remote Sensing?

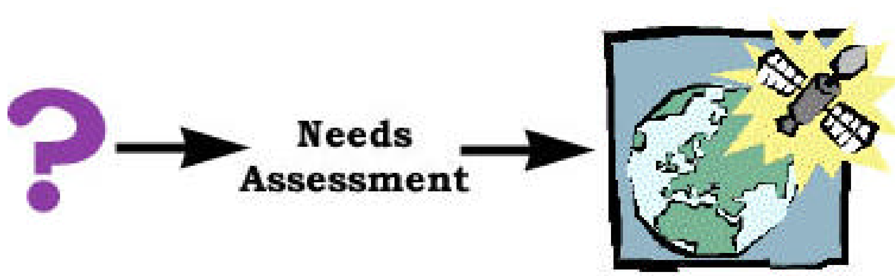
The broadest definition of remote sensing could include the collection of information about any feature using any device from a remote location. Rendering a landscape with a paintbrush or reading a book with your eyes could be considered remote sensing. The definition with which many people are familiar is described as earth observation remote sensing. It includes specific types of instruments that are flown aboard planes and satellites and designed to collect data about the earth's surface (Lillesand and Keifer, 1994). Refer to the appendix to read more about the sensors discussed in this document.

Many of the remote sensing data products available today are the result of military research and development that occurred throughout the Cold War. High-resolution photography, radar, and thermal detection sensors were indispensable tools for military success from World War II to the present day. In the hands of the commercial and civilian sectors, these kinds of technologies are now applied to a wide scope of environmental problems (Campbell and Erickson, 1995).

Applications

There are countless potential resource management applications of remotely-sensed data in our region. Oceanographers have used satellite data to map currents and temperature fronts, as well as concentrations of phytoplankton. Radar data has been used to locate icebergs and oil slicks. The forest industry has used satellite information to inventory stands and monitor forest health. In agriculture, radar and satellite data has helped isolate invasive plants and monitor soil moisture and crop disease. Urban and regional planners use fine spatial resolution data to map changing human patterns and their impact on the natural landscape. Section four of this document goes into more detail, outlining four regional applications of remotely-sensed data.

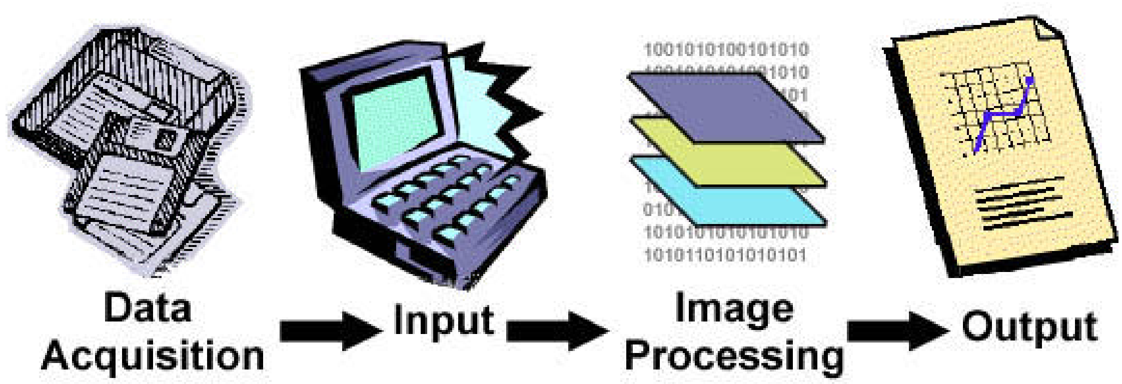
Is Remote Sensing the Right Solution?



Despite its widespread application, remote sensing is far from being a panacea. It represents just one possible solution for the scores of ecological questions faced today. The best way to know if it is the *right* solution is by conducting a thorough planning process. Spatial analysis begins with a well-formulated question, followed by a needs assessment based on the space and time scales necessary to answer the question. It then incorporates these parameters in the identification of an appropriate solution. Depending on a number of factors including costs, available expertise and infrastructure, the solution may be a product derived from remote sensing.

Data Acquisition and Processing

Once a remote sensing product is identified, the core of the work begins. This is known as data acquisition and processing, and generally involves four steps. First, the data must be acquired using the time and space parameters outlined in the planning process. The imagery must then be imported to a computer system where it is spatially referenced and calibrated. Next the imagery is processed, which involves some combination of display, interpretation, and classification. The final step is the output of data in a format that can be understood by managers and others who will use the data (NOAA, 1997). This last step may involve integrating GIS or similar software for comparing the remotely-sensed imagery with other data.



II. Elements of remote sensing

Today, an overwhelming variety of airborne and satellite instruments owned by numerous private companies and government agencies collect data around the world. In order to work through the planning process outlined above, there are several major elements of remote sensing that must be understood. These include resolution, spectral signatures, radar, image interpretation and image classification, which are outlined below.

Resolution

Resolution is vital to understanding all remote sensing instruments. There are four types of resolution: spatial, spectral, temporal, and radiometric. In describing a sensor's resolution, it is vital to clarify which *type* of resolution is being discussed. An instrument that measures the earth with fine *spatial* resolution may have very coarse *spectral* resolution. In any application of remotely-sensed data, these trade-offs must be carefully considered.

Spatial resolution refers to the size of the smallest object that can be discerned in an image. Digital remotely-sensed images are made up of rows and columns of equal-sized squares called *cells* or *pixels.* The dimensions of a single cell generally represent the spatial resolution of the image. The images from weather satellites displayed on the evening news are made up of very large cells, usually 1 km or more (Campbell and Erickson, 1995). This kind of resolution is suitable for meteorologists, who look at global patterns. In contrast, some of the latest available satellite data boasts spatial resolutions of 5 meters and less. This data is currently expensive, but extremely useful for mapping local features such as roads, buildings, and utility corridors.

Passive vs. Active Sensors

Remote sensing instruments fall within two major divisions: *active* and *passive.* Both types of instruments record radiation traveling from the earth outward into space. The major difference between active and passive instruments is the origin of radiation – an active instrument provides its own source of radiation and measures its reflection from the earth. A good example is radar, which sends a pulse of energy and measures its strength upon return. Passive instruments measure existing sources of radiation (either solar radiation reflected or emitted by the earth or radiation emitted from an object such as a heated building). Individual instruments within these two divisions detect radiation travelling at different wavelengths and answer different questions about our environment. To understand the advantages of each instrument, one must consider the major elements of remote sensing.

Temporal resolution refers to an instrument's frequency of coverage, which is the time it takes to acquire successive images of the same place on earth. This is determined by the swath of an instrument (the ground width it can cover in a single pass), as well as its orbit (Lillesand and Keifer, 1994). Frequency of coverage is vital to meteorologists, who monitor a continuously changing atmosphere. Therefore, most weather satellites are placed in geostationary orbit and maintain their position above the same point on the globe at all times, day and night (Fig. 1). Aircraft-mounted sensors aren't constrained by specific orbits, but may be grounded for days by local weather conditions.

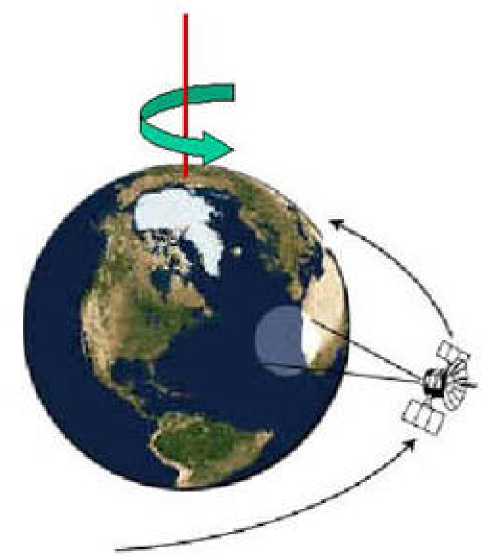


Figure 1. **Geostationary Orbit**
(adapted from Canada Centre for RS, 1999)

Most of the satellites discussed in this paper circle the earth in a near-polar, sun-synchronous orbit (Fig. 2). This means the satellite can image the same area of the globe at the same local time each time it returns, which helps maintain consistent sun angles and shadows in the imagery, and allows analysts to make comparisons between images over time (Thomas, personal communication, 1999). Some of these satellites take more than two weeks to image the same area of the globe, while others return twice a day.

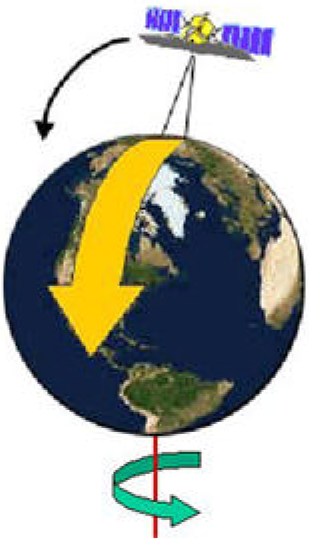


Figure 2. Near-polar orbit
(adapted from Canada Centre for RS, 1999)

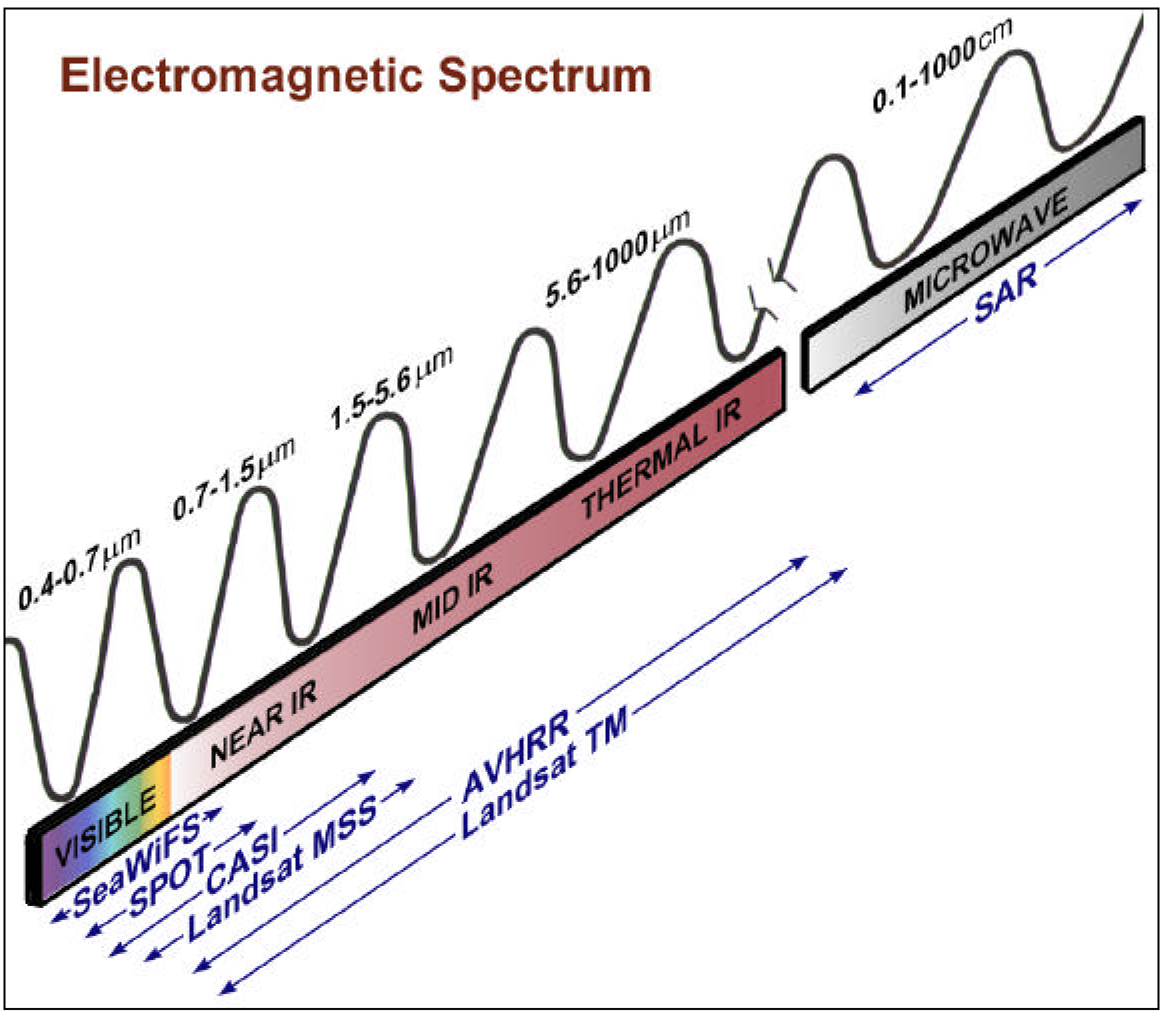


Figure 3. Electromagnetic Spectrum (Adapted from Christensen, 1995)

Spectral resolution refers to the number and width of areas along the electromagnetic spectrum that a sensor 'sees'. Remote sensing instruments are designed to collect information using the varying wavelengths in which electromagnetic energy travels (Fig. 3). Each area conveys a unique set of information about the earth's surface. Spectral resolution applies only to multispectral data.

Spectral Signatures

Multispectral data gives analysts the ability to distinguish between unique objects or surfaces that otherwise appear similar. Multispectral data takes advantage of an object's spectral signature - the unique spectral response which defines it. Spectral signatures are identified by collecting data over relatively homogenous terrain at various wavelengths (Lillesand and Keifer, 1994).

As their colors suggest, water reflects a significant amount of blue light and vegetation reflects green light within the visible spectrum. Using this intuitive knowledge we could easily separate forests from lakes in a true-color satellite image. Separating spruce trees from fir would prove more difficult since their color and shape are similar.

Spruce and fir are easier to distinguish in a region just outside the visible spectrum, where they each have a unique spectral signature. This portion of the spectrum is referred to as near infrared radiation (IR), and its wavelengths are slightly longer than those we can see (Fig. 3).

Panchromatic, Multispectral, and Hyperspectral

Panchromatic data does not distinguish between portions of the visible spectrum, and therefore resembles black and white photography. Most of the instruments discussed in this paper are multispectral, meaning they differentiate between portions of the spectrum. Using image processing techniques, scientists can take advantage of unique combinations within multispectral imagery to reveal hidden patterns in the data.

In recent years, a new generation of *hyperspectral* sensors has appeared. These instruments divide portions of the spectrum into numerous discrete ranges, which are designed to detect very specific environmental features such as a particular plant species or sediment type. Most of these sensors operate on aircraft platforms, giving the user tremendous flexibility in where and when an area is imaged. Currently, the high cost of obtaining and analyzing hyperspectral data makes it infeasible for many potential users.

Other portions of the spectrum are useful for specific feature identification. Microwaves, which are some of the longest wavelengths used in remote sensing, are ideal for identifying surface texture. Radar utilizes the microwave range by emitting its own signal and measuring the return time of its echoes (Weatherbee, personal communication, 1999). These measurements highlight surface texture, which is ideal for mapping features such as topography and sea surface condition. Radar imagery is created using a single portion of the spectrum, so it cannot be classified like multispectral data is.

Image Classification

A multispectral image is actually a three-dimensional matrix, where each cell is represented by multiple values – one value for each band in the data. Image classification, the process of categorizing similar values, reduces the data to a single value at each pixel. If executed correctly, each class or range of values in a classified image will represent a unique element on the earth's surface. An accurate final product usually requires the execution of several classification routines for the image to closely match features on the ground.

The features of interest derived from image classification are generally identified before image processing occurs. Analysts may develop their own classification scheme, or borrow from someone else. A classification scheme should only be as detailed as the feature of interest. For instance, if forest needs to be distinguished from field, no more than three classes of vegetation (forest, field, and other) may be necessary. In contrast, a detailed forest inventory would require mapping distinct species. The classification scheme may be larger, and hierarchical in structure to include major classes of deciduous and coniferous and minor classes of birch, spruce, fir, maple, etc.

The degree to which surface features in an image can be categorized depends on several factors including image resolution (spatial, spectral, radiometric, and temporal) and the analyst's knowledge of the region. Where local knowledge is absent, additional field-truthing is necessary. This involves the identification of features on the ground, which

North Atlantic Observatory:
A center for remote sensing in Maine

In broad terms, remote sensing can include data collected by any instrument in a remote location, whether it is several miles into space or several leagues beneath the sea. Today, remotely-operated submersibles can send data about seafloor conditions to the surface, where they can be compared to historical fish spawning areas to create habitat maps. Similarly, lobster catch data recorded by lobstermen can be combined with images of sea surface temperature to identify patterns of lobster settlement and abundance.

A centrally-located remote sensing facility in our region could utilize emerging spatial technologies to promote cooperation between those who have traditionally been at odds with one another: scientists, policy-makers, and resource users. Such a center could utilize remotely-sensed data collected by fishermen aboard boats and volunteers on the shore, as well as the more sophisticated sources discussed in this document. By taking advantage of the existing research infrastructure in the state, and reaching out to resource users, such a center could help bridge the gaps between resource use, management, and scientific knowledge.

A regional remote sensing center in Maine will act as an independent entity, designed as a central facility for the storage, synthesis and distribution of data. Such a center could become a catalyst for the enhancement of Maine's research community by promoting cooperation and attracting research dollars. The center could also lead to the development of commercially viable products as well as new sensors.

are then used as seed pixels to classify the rest of an image. Field truthing is most effective when classifying recently acquired imagery, or in regions where surface features change slowly. With older images, or ones that highlight dynamic patterns such as suburban sprawl, ancillary data sources are helpful in identifying historical patterns. These might include topographic maps, air photos, or other kinds of remotely sensed data created around the same time.

Multispectral image interpretation does not always involve classification. The visible bands in Landsat data can be displayed as a true color composite for mapping or large-scale landscape analysis. Some combinations of bands, called band ratios, can differentiate features without classification, and occasionally a single band will tell the whole story. (Campbell and Erickson, 1995).

Despite its versatility, multispectral data is not the right remote sensing solution for every problem. Other types of instruments such as radar and aerial photography are very effective for certain applications. Radar data is unique from multispectral in a number of ways. It doesn't involve the same type of image processing techniques, but its interpretation requires sophisticated knowledge. Radar is able to answer a wealth of questions not addressed by other forms of remote sensing.

Radar Instruments

Radar (**ra**dio **d**etection **a**nd **r**anging), was developed to utilize the very long wavelengths of the radio band of the spectrum. Unlike the sensors just discussed, radar is an active sensor, meaning it sends out a pulse of microwave radiation and then receives the reflection from the target. In this sense, radar is similar to sonar, which uses sound waves to detect underwater features. The reflected component of radar is known as echo or backscatter. Because it uses the radiation of single wavelengths, radar imagery is monochromatic. The primary application of radar is the interpretation and measurement of land and sea surface features including topography and surface roughness (Canada Centre for Remote Sensing, 1999).

Because it provides its own radiation, radar can be operated during the day or night. Additionally, the angle and direction of illumination can be controlled to highlight and enhance features of interest. The long wavelengths of microwave energy travel through clouds and precipitation without hindrance, and can penetrate features such as snow, dust, haze and sand. Understanding the data collected by radar requires an examination of radar geometry.

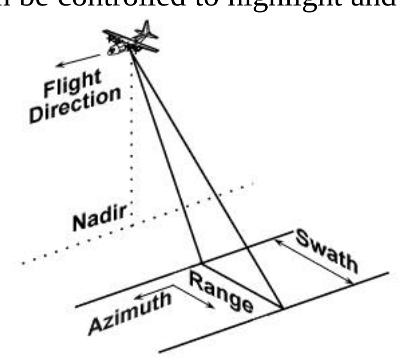


Figure 4. Radar Geometry
(Adapted from Canada CRS, 1999)

The geometry of a radar system is different from the scanning systems described previously (Fig. 4). Like those systems, the radar instrument moves along the flight direction, directly above the nadir. The microwave beam is directed outward from the aircraft at an oblique right angle and illuminates a swath, parallel to the flight direction. In a radar image, azimuth refers to the dimension along the flight direction, whose resolution is determined by the frequency of the radar pulse. Range describes the across-track dimension, which can be a subset of the swath (Canada Centre for Remote Sensing, 1999).

Other dimensions that are important for understanding the data derived from radar instruments include the angles of view (Fig. 5). Look angle describes how steeply the radar is viewing the earth's surface. Large look angles result in high image distortion, but can help reveal subtle textures. Incidence angle is the angle between the radar beam and the ground surface. In the near range, the incidence angle is smaller and image distortion is less than in the far range, furthest away from the plane's flight path. Spatial resolution is based on the azimuth and range dimensions and the look angle (Canada Center for Remote Sensing, 1999).

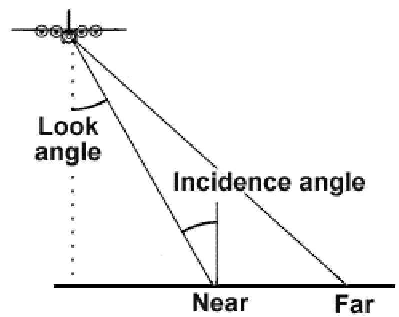


Figure 5. Angles of View
(Adapted from Canada CRS, 1999)

Synthetic Aperture Radar

The latest generation of radar, known as synthetic aperture radar (SAR), is a product of the Cold War. It was designed to collect fine resolution data from further distances, such as satellites. In radar data, larger antennas generally offer better spatial resolution. It is infeasible to put large antennas on spacecraft due to cost and weight considerations, but smaller antennas would result in poor image resolution from such great distances.

To overcome these constraints, researchers developed a method for simulating a large antenna by utilizing spacecraft motion. A single spaceborne SAR instrument can collect hundreds of pulses a second to image features with spatial resolutions of 30 meters and less. The ERS-1 satellite can keep an object in view for about 4 km, while receiving thousands of backscattered responses, yet it carries an antenna only 10 meters long. Thus it can simulate an antenna 400 times its size, which is what makes SAR such a valuable tool. It is also important to note that SAR imagery is subject to the same principles of geometry as any radar system (Kramer, 1992).

SAR: Airborne vs. Spaceborne

As with other remote sensing systems, SAR can be mounted on aircraft or spacecraft. Resolution of SAR imagery is independent of platform type, but there remain trade-offs between the two. The advantages of spaceborne SAR include imaging at small look angles, which add less image distortion. The uniform platform and orbit eliminate the extensive pre-processing needed to correct for aircraft movement in airborne data.

Airborne SAR is more versatile – it can be collected anywhere at anytime, as long as weather conditions are favorable for flying. Two SAR instruments, AirSAR and RADARSAT are described in the appendix of this document. (Canada Centre for Remote Sensing, 1999).

III. Limitations of Remote Sensing

Satellites see only the surface

With a few exceptions, most remote sensing instruments can only image the surface of the earth. For example, AVHRR collects data about sea surface temperature, but these data only reveal the ocean's "skin" temperature—the first few millimeters below the surface. Subsurface conditions must be collected with other kinds of instruments mounted on buoys and submersibles.

Time and space scales

Because most instruments are designed for the widest array of possible applications, there is no perfect instrument for every resource management problem. Instead, the best fit for any application involves trade-offs between time and space scales. Figure 5 illustrates the time and space domains for several coastal resource management issues. These are compared to the spatial and temporal coverage provided by two remote sensing instruments, AVHRR and Landsat TM. There are other sensors that might cover greater portions of these resource issues, but in many cases the issue itself cannot be resolved with remote sensing. Instead, remotely-sensed data provides information about related features that may affect a particular issue. For instance, harmful algal blooms cannot be identified with AVHRR imagery, but the data can identify persistent ocean currents that help determine where blooms may occur.

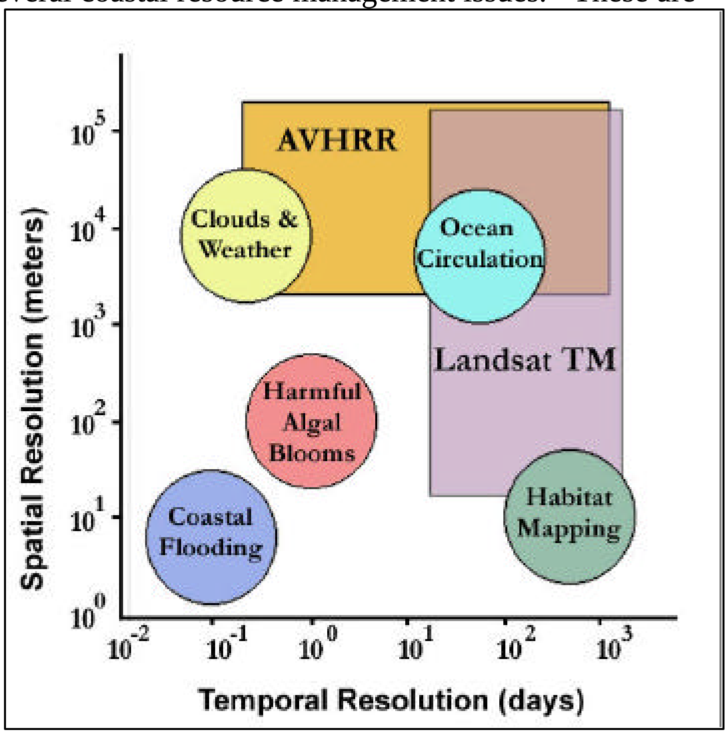


Figure 6. Time and Space Scales
(Adapted from NOAA, 1997)

Atmospheric Conditions

For most sensors, clouds, fog, haze, pollution, dust and other particulates affect the interpretation of imagery. Clouds and fog can completely obscure a satellite scene, forcing the analyst to wait for the next pass of the satellite. Haze and particulates change the spectral response of ground features, so imagery must be calibrated to ensure it is accurate. Radar and other long-wave sensors avoid atmospheric limitations, but these instruments are not suitable for many applications.

Field measurements

Most image processing requires *in situ* measurements that are used to calibrate the data. Many potential users see remote sensing as an alternative to field work, but some field truthing is almost always necessary to create an accurate final product.

Cost

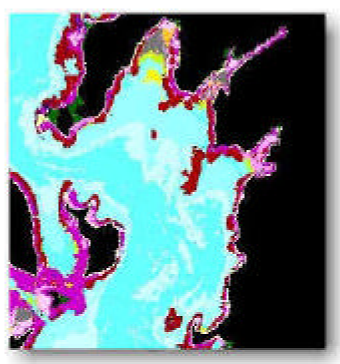
Although advances in technology have brought sophisticated image processing tools to the desktop, remote sensing is still a costly enterprise. Measured in dollars and time, it creates tremendous overhead for any organization. Software and hardware maintenance, data acquisition, staff resources and training are all part of implementing this capability. Fortunately, there are many agencies and private companies that have the infrastructure in place and can assist with the most costly aspects of digital image processing.

IV. Applications of Remote Sensing

Despite the limitations, there are countless examples of successful applications of remote sensing to the environment. The following summaries encompass several of these applications in the Gulf of Maine region. While the summaries don't begin to address the enormous capabilities and scope of remote sensing data available, they give some insight into how this data is being utilized in real-world situations. The summaries encompass a wide variety of data applied to upland, intertidal, and marine environments around the region.

CASI: Mapping the intertidal region

Based on: *Intertidal Habitat Definition and Mapping in Penobscot Bay*
Peter Foster Larsen, Ph.D. And Cynthia B. Erickson
Bigelow Laboratory for Ocean Sciences



During the first two years of the Penobscot Bay Marine Resources Collaborative administered by the Island Institute, an effort was made to map the intertidal region of several key areas using high resolution imagery. In August of 1997, G.A. Borstad Associates Ltd. of British Columbia collected data with a CASI instrument over several areas of Penobscot Bay. These flights were scheduled for low-tide times and relatively cloud-free skies. Eleven spectral bands were used to image the region which included parts of Owls Head and South Thomaston, and the entire island of Islesboro, Maine. The bands included 3 portions of the near infrared region as well as seven bands within the visible spectrum.

The raw CASI data was transferred to Borstad headquarters and processed to correct for aircraft movement. The data was then compared to other satellite information and georeferenced so that it could be used with other geographic data. Finally, the CASI data was exported as ERDAS Imagine files and transferred to Bigelow Laboratory in Boothbay Harbor, Maine for classification.

Beginning in 1997, Peter Larsen and Cynthia Erickson of Bigelow Laboratory used the CASI data to conduct an image classification focused on the intertidal region. Their work began with a visit to the Washington Department of Natural Resources in Olympia, WA. WDNR has had great success in using a CASI instrument to develop data about the intertidal regions of Puget Sound. Erickson and Larsen spent more than a week learning the processing techniques unique to CASI data.

Armed with an understanding of CASI image classification and field calibration techniques, the researchers returned to Maine to begin their analysis. The first step in the classification process was the development of a classification scheme. The scheme had to account for the capabilities of the instrument and habitat patterns on the ground. Since the application was focused on a set of highly associated natural features, the scheme's creation required a great deal of research. The scientists looked at several unique ecological classification systems, and drew upon their own knowledge of intertidal regions within the Gulf of Maine to develop a scheme specific to this analysis.

A series of study sites was identified using field visits and reference data that included maps and aerial photographs. The goal of identifying study sites is to create a comprehensive picture of the ecological diversity of the study region without having to visit the entire area. These sites then become references in the image data for areas with which the researchers are less familiar. With these sites identified, the final preparation for classification involved eliminating data outside the intertidal zone, for more focused image processing. This step, which is called masking, conserves time spent on computer processing and image interpretation.

With these steps complete, the researchers moved to the core of their analysis. A rigorous classification procedure was conducted on the CASI data, involving thirty distinct steps which led to the final intertidal maps. First, the image was subjected to a supervised classification, in which the computer utilizes known information about the region and groups the image pixels accordingly.

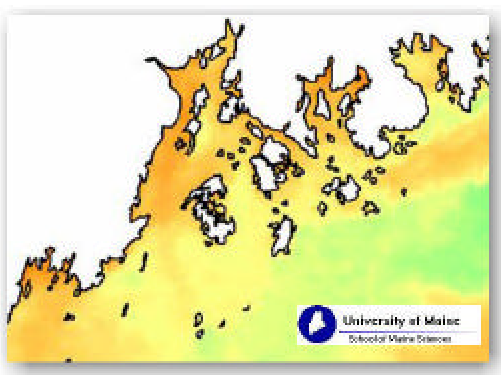
The researchers used an iterative process in which several more unsupervised classifications were conducted to produce the final product. In an unsupervised classification, the computer looks for spectral breaks in the data and groups pixels accordingly. After each of these, misclassified pixels were given a common data value and masked, so that processing could focus on the known data. The goal of iterative classification and masking is to develop spectral signatures for each feature of interest.

At three key points in the process, edited images were saved and retained to create the final image. The final composite was derived using a model that combined the three edited images while allowing the correctly classified pixels from each to be displayed. This final image was then tweaked and recoded using appropriate colors and feature names. Misclassified pixels were edited, and some pixels in the final map remained unknown. Fifteen vegetation and substrate classes were defined, in addition to general water and upland classes. The final product was output in several file formats including ERDAS Imagine and ArcInfo Grid. Example images can be found at the Penobscot Bay Project website: www.islandinstitute.org/penbay.

AVHRR and SeaWiFS: Examining oceanographic conditions over time

Based on: *Retrospective Satellite Data Analysis*
Andrew Thomas, Ph.D.
University of Maine School of Marine Sciences

In 1998 Dr. Andrew Thomas of the University of Maine School of Marine Sciences conducted data analysis on two sets of archived satellite image data. These datasets were acquired from the AVHRR and SeaWiFS sensors and include data from 1990 to 1995 and October, 1997 to June, 1998, respectively. In both analyses the goal was to develop a picture of mean seasonal variability in Penobscot Bay. The AVHRR study focused on sea surface temperature patterns, while the SeaWiFS analysis highlighted chlorophyll concentrations.



The SeaWiFS data was acquired in High Resolution Picture Transmission format and used to produce monthly averages of chlorophyll concentration in and near Penobscot Bay. These monthly composites were created by calculating the average value of candidate pixels throughout a single month of images. Candidate pixels were those within the study area that had a value greater than zero. Monthly average images were produced for each month between October, 1997 and June, 1998.

Thomas also computed monthly variability images from the SeaWiFS data. The cell values in these images represent either the root mean square or standard deviation of the candidate pixel values used to compute the monthly averages. This data provides an indication of the variability in chlorophyll concentrations through time and space in Penobscot Bay. All of the images were then exported to ArcInfo GRID format for compatibility with other geo-referenced data. Because SeaWiFS is a very new sensor the study incorporated less than a year's worth of data.

Thomas' study of AVHRR data drew on a much larger set of images in order to develop a picture of broad-scale sea surface temperature patterns in and near Penobscot Bay. He utilized nearly 8000 images collected four times a day between 1990 and 1995. A significant amount of data was generated from this study, which includes daily, monthly, and seasonal composites of the original products.

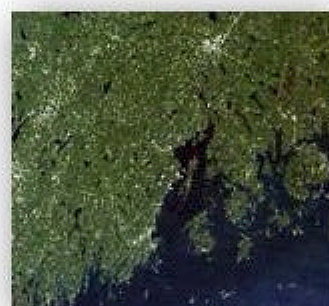
A daily composite was created for each day of the year by calculating the average value of each pixel across all images. Depending on atmospheric interference, each cell in a daily composite image represented the average of 1 to 6 pixels. Throughout all the composites, land pixels were not analyzed. A monthly and seasonal (fall, winter, spring, summer) composite was created for each year of data in the same manner. For example, to create a composite of Fall, 1990 data, Thomas averaged the pixels from October, November and December of that year.

With monthly and seasonal composites created for each of the six years, Thomas was able to average each month and season across the time period. In this manner he developed final images illustrating monthly and seasonal sea surface temperature patterns over six years. The confidence of the monthly and seasonal composites was influenced by the number of candidate pixels in the original average, which in turn were affected by atmospheric conditions and anomalies in the data. The six year composites help to average the variation in weather conditions from one year to the next and reveal clearer patterns in sea surface temperature.

Sea surface temperature data frequently correspond to ocean currents, allowing one to see the potential patterns of resource distribution. Thomas' data clearly illustrates the presence of cold water features, particularly the Eastern Maine Coastal Current, which is thought to influence the ecology along the Gulf of Maine's perimeter. Marine mammals, fish, plankton and human-induced hazards like oil spills are all subject to these patterns of circulation. Thomas' work highlights the usefulness of large-scale data such as SeaWiFS and AVHRR to identify and monitor regional patterns over time.

Landsat TM: Capturing a dynamic landscape

Based on: *Land Cover Change Detection of Penobscot Bay*
Nicholas (Miki) Schmidt
NOAA Coastal Services Center



The Coastal Change Analysis Program (CCAP) within NOAA's Coastal Services Center recently created a land cover change detection product of the area surrounding Penobscot Bay. CCAP has developed a rigorous image processing methodology which utilizes Landsat TM data and involves extensive field checking. The goal of CCAP is to develop a database of landcover and habitat change for the coastal and Great Lakes regions of the U.S. Change detection is a common application within the field of remote sensing. It requires a temporally rich data source and consistent processing, along with extensive field work to ensure the final product is accurate.

In Penobscot Bay, remote sensing scientists were challenged with a variety of landscapes, including wetlands and diverse agricultural areas. These elements make landcover classification extremely challenging. Wetlands are particularly difficult to classify in Landsat TM data. The amount of water present in an individual pixel taints the signature of vegetation, making it difficult to distinguish between different species types. In order to combat this problem, CCAP scientists use a combination of ancillary data sources such as aerial photography and extensive field work to address potential classification errors.

Change detection requires two cloud-free images from separate dates, preferably far enough apart for obvious change to have occurred. The next step is the identification of training sites in preparation for classification. Sites are chosen based on how universally they represent a particular landcover type within the region. CCAP scientists frequently utilize local experts to identify such areas. These training site pixels become the focus of an iterative classification routine which develops spectral signatures for each cover type and groups the pixels accordingly. This supervised classification is followed by several unsupervised classifications and image combinations which result in an interim product to be field checked and analyzed further.

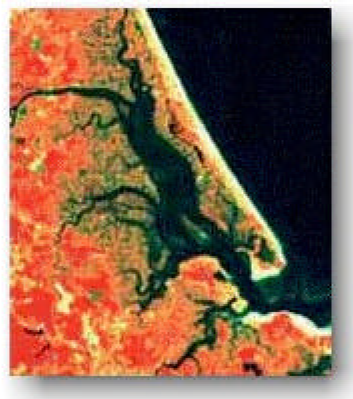
Probably the most important aspect of the CCAP protocol is its emphasis on local knowledge and field work. This effort is focused on the most recent of the two images that are part of the study. Because they assume that significant change has occurred between image dates, the analysts rely on ancillary data in order to classify the earlier image. Before the recent image is processed, scientists visit the study area and work with local biologists to identify training sites. Using GPS, these areas are located and recorded as digital files. Back in the office, these GIS files are overlaid on the satellite image in order to develop spectral signatures for each of the 15 cover types. CCAP has identified these fifteen classes as a way of making their products consistent no matter which part of the country they cover.

Once a suitable classification is conducted, the image is transported back to the study area on a powerful laptop computer. Using a vehicle-mounted GPS, analysts drive through the study area, comparing pixels in the image classification to what they see in the same spot on the ground. Discrepancies are flagged and recorded digitally. These problem areas are then isolated and carefully reclassified back at the office. Conducting on-site error identification is extremely resource intensive, but ensures a highly accurate final product.

Once the classification of the recent image is complete it can be combined with the early classification to identify those areas that have changed over time. Each pixel in this change image has a value indicating whether or not change occurred, as well as the current landcover type, and the old landcover type. All products are saved in ArcInfo GRID format, so they can be used with other geographic data.

With the finished product in hand, analysts returned to the study area a final time to develop an accuracy assessment. A value was derived for each of the fifteen landcover classes describing how accurately it was identified. Problem classes in midcoast Maine included forested wetlands, scrub-shrub and cultivated land. Blueberry fields, which cover a significant portion of the Penobscot Bay image, were frequently confused with other features. These classes received lower accuracy percentages than more easily defined ones such as water or highly-developed land. Despite these challenges, the final product is highly accurate spatial data that can be utilized for landscape-scale GIS modeling and mapping.

SPOT: Delineating Wetlands
Based on: *Ipswich Bay: A Closer Look*
Christopher E. Brehme
Island Institute



In the fall of 1997, the author analyzed a set of SPOT data from northeastern Massachusetts to delineate wetland features and highlight change over time. Wetlands delineation has proved consistently challenging in remote sensing, despite the availability of high resolution data. The keys to wetlands analysis are isolating water in the imagery and understanding the range of signatures a single vegetation species can have in varying environments. For example, spartina grasses exhibit varying reflectance values based on the amount of surface water visible in their immediate area.

In this study of Great Marsh, Massachusetts we created subgroups of intertidal, open marsh, and high marsh vegetation. The data available to us included panchromatic digital orthophotos with 1 meter spatial resolution, 7.5’ USGS topographic maps and NOAA nautical charts. In addition to quantifying wetlands in the region, we intended to create maps of change over time using historical and recent SPOT data. Some of the challenges faced included a large tidal range (8 feet), and a limited growing season. Winter snow and ice in the region also causes marsh grasses to be matted down between November and April. These factors threatened the accuracy of a change detection product.

In addition to the ancillary data sources mentioned above, we made two field trips to the study area with a GPS receiver in order to delineate ‘pure’ stands of vegetation including spartina, cattails, phragmites, and intertidal areas. Using standard image processing tools, we conducted unsupervised and supervised classifications and combined the results in order to identify the best fit for our features of interest. The process included the creation of masks for water and upland areas, so our analysis could concentrate on the saltmarsh.

Eventually we created two final images, one from 1996 and another from 1989. The ancillary data sources mentioned above proved useful for creating a classification of the earlier SPOT image. The results were then transferred to ESRI ArcInfo Grids and imported into ESRI ArcView 3.0. Using a raster (cell-based) processing extension known as Spatial Analyst, the results were combined to identify those cells that changed over the seven year period.

The resulting data was taken back to the field and compared to conditions on the ground, and each class within the data was analyzed for accuracy. The results showed that open areas where water conditions were easy to ascertain were well classified. Taller marsh vegetation such as cattails and phragmites were much more difficult to isolate, and were frequently confused with scrub-shrub and spartina grasses.

Classifications schemes that included water and upland areas were executed to create a more comprehensive dataset for the region. Classes of shallow and deep water, scrub-shrub, forest, sand and developed areas were created. All of the finished data was saved in GIS format to be used with other spatial data in the future.

V. Conclusion

These applications should provide some insight into the versatility of satellite and airborne remotely-sensed data for answering environmental questions. The instruments outlined in these analyses include some of the more commonly known sensors, such as Landsat and SPOT. These satellite programs continue to thrive and improve their capabilities with the recent launch of Landsat 7 in early 1999 and SPOT 4 in 1998.

There are many other sensors and systems that continue to evolve and close the gap between user needs and technical capability. At the same time, archives of data are piling up, leaving anyone the opportunity to examine changing conditions over time. Retrospective analysis like the one described above provide a valuable baseline for examining related phenomenon. For example, changes in mean sea surface temperature patterns could be correlated with fluctuating fish stocks or lobster settlement patterns. On land, dynamic patterns such as suburban sprawl and coastal development can be monitored through ongoing efforts such as NOAA's Coastal Change Analysis Program.

Through an examination of these efforts, this document just glimpses the frontier of a potentially boundless new science. Remote sensing offers enormous opportunity for examining the environment, monitoring its health, and making predictions about future conditions. As the costs of the technology decrease and its utility increases, more and more scientists, managers and resource users will become proficient in remote sensing. At the same time, we hope these tools are used wisely and continue to contribute positively to our knowledge of the environment.

VI. References

Brehme, Chris, *Ipswich Bay: A Closer Look*. In *Rim of the Gulf: Restoring Estuaries in the Gulf of Maine*. Rockland, ME: Island Institute, 1998.

Campbell, Janet W. and Erickson, Cynthia B. In *From Cape Cod to the Bay of Fundy: An Environmental Atlas of the Gulf of Maine*. Philip Conkling, editor. Cambridge, MA: MIT Press, 1995.

Campbell, J.W.M. and Vachon, P.W., *Quantitative Demonstration of RADARSAT SAR Data for Selected Ocean Applications*. In Proceedings of the Fourth International Conference on Remote Sensing for Marine and Coastal Environments, Orlando, FL, March 17 –19, 1997. Ann Arbor: Environmental Research Institute of Michigan, 1997.

Canada Centre for Remote Sensing, World Wide Web site: http://www.ccrs.nrcan.gc.ca

Chritensen, T., Electromagnetic Spectrum (Image). In *From Cape Cod to the Bay of Fundy: An Environmental Atlas of the Gulf of Maine*. Philip Conkling, editor. Cambridge, MA: MIT Press, 1995.

Drury, S.A., *Images of the Earth: a Guide to Remote Sensing*. Oxford: Oxford University Press, 1998.

From Cape Cod to the Bay of Fundy: An Environmental Atlas of the Gulf of Maine. Philip Conkling, editor. Cambridge, MA: MIT Press, 1995.

Guide to Satellite Remote Sensing of the Marine Environment. Washington: UNESCO Intergovernmental Oceanographic Commission, 1992.

Kramer, H.J., *Earth Observation Remote Sensing: Survey of Missions and Sensors*. Berlin: Springer-Verlag, 1992.

Larsen, Peter F. and Erickson, Cynthia B., *Intertidal Habitat Definition and Mapping in Penobscot Bay*. Report to NOAA-NESDIS Penobscot Bay Marine Resource Collaborative, 1998 (unpublished).

Lillesand, Thomas M. and Keifer, Ralph W., *Remote Sensing and Image Interpretation.* New York: John Wiley & Sons, 1994.

Lou, Y., Kim, Y. and van Zyl, J., *The NASA/JPL Airborne Synthetic Aperture Radar System*. Pasadena, CA: Jet Propulsion Laboratory, 1996.

National Oceanic and Atmospheric Administration, *Operational Use of Civil Space-Based Synthetic Aperture Radar (SAR)*. Washington, DC: Interagency Ad Hoc Working Group on SAR, 1996.

National Oceanic and Atmospheric Administration, *Remote Sensing for Coastal Resource Managers: An Overview.* Washington, DC: National Ocean Service, 1997.

Oceanographic Applications of Remote Sensing, Motoyoshi Ikeda and Frederic Dobson, editors. Boca Raton: CRC Press, 1995.

Schmidt, N., *Land Cover Change Detection with Landsat TM Data.* Report to NOAA-NESDIS Penobscot Bay Marine Resource Collaborative, 1998 (unpublished).

Thomas, Andrew, *Retrospective Satellite Data Analysis*. Report to NOAA-NESDIS Penobscot Bay Marine Resource Collaborative, 1998 (unpublished).

Thomas, Andrew, University of Maine School of Marine Sciences, personal communication April 1, 1999.

U.S. Congress, Office of Technology Assessment, *Civilian Satellite Remote Sensing: A Strategic Approach*, OTA-ISS-607. Washington DC: US Government Printing Office, 1994.

Victorov, Serge, *Regional Satellite Oceanography.* London: Taylor & Francis, 1996.

Weatherbee, Ryan, University of Maine School of Marine Sciences, personal communication April 1, 1999.

Appendix. Individual Instrument Descriptions

The pages that follow provide an outline of several remote sensing instruments which have applicability to the waters and coastal areas of the Gulf of Maine. Within the outline of each sensor is a description of the instrument and a list of vital statistics including resolution, data availability and contact information.

AVHRR

The Advanced Very High Resolution Radiometer (AVHRR) is one of the most widely used oceanographic monitoring satellites. The scanner collects information in five bands which include the visible, near-infrared, and thermal infrared portions of the electromagnetic spectrum.

AVHRR data are acquired in three formats: High Resolution Picture Transmission (HRPT) images are transmitted to a ground station in real-time. Local Area Coverage (LAC) data are the same images recorded on tape for later transmission. Global Area Coverage (GAC) represents imagery that is resampled to 4 km.

Vital Statistics
Operator: NOAA
Dates of Operation: 10/13/78 to present on TIROS-N and NOAA-6 through 14 satellites (NOAA 10,11,12,14 & 15 currently active)
Spatial Resolution: 1.1 km (LAC and HRPT) and 4 km (GAC)
Temporal Resolution: twice/day
Spectral Resolution:

Band	1	2	3	4	5
Wavelength (mm)	.58 to .68	.725 to 1.10	3.55 to 3.93	10.3 to 11.3	11.5 to 12.5

Radiometric Resolution: 10 bit
Orbit: near polar, sun-synchronous, 833 km in altitude
Swath Width : 2399 km
Data acquisition:

Customer Services U.S. Geological Survey EROS Data Center 47914 252nd Street Sioux Falls, SD 57198-0001 Tel: (605) 594-6151 or 1-800-252-GLIS Fax: (605) 594-6589 custserv@edcmail.cr.usgs.gov edcwww.cr.usgs.gov/eros-home.html	NOAA/SAA User Assistance National Climatic Data Center Climate Services Division 151 Patton Avenue Asheville, NC 28801-5001 Tel: (704) 271-4800 Fax: (704) 271-4876 Saainfo@nesdis.noaa.gov Www2.ncdc.noaa.gov/POD/c6/sect6.html

Applications:
Primary use is the measurement of sea surface temperature.
Source: NOAA

SeaWiFS

The Sea-viewing Wide-Field-of View Sensor (SeaWiFS) on board the SeaStar spacecraft is an advanced sensor designed for ocean monitoring, specifically the observation of ocean color. The SeaWiFS sensor consists of eight spectral bands of very narrow wavelength ranges tailored for very specific detection and monitoring of various ocean phenomena including ocean primary production and phytoplankton processes. These applications require calibration with *in situ* data.

As with AVHRR data, SeaWiFS is available in three formats: High Resolution Picture Transmission (HRPT), which is real-time data and Local Area Coverage (LAC), which is recorded data, have a spatial resolution of .88 km and swath width of 2800 km. Global Area Coverage (GAC), has a spatial resolution of 4 km and a swath width of 1500 km.

<u>Vital Statistics</u>
Operator: Collaboration between NASA and Orbimage
Dates of Operation: 9/18/97 to present
Spatial Resolution: .88 km (LAC and HRPT) and 4 km (GAC) (scanner can be tilted 20 degrees from nadir in either direction)
Temporal Resolution: 1 visit/day
Spectral Resolution:

Band	1	2	3	4	5	6	7	8
Wavelength (mm)	.402-.422	.433-.453	.48-.5	.5-.52	.545-.563	.66-.68	.745-.785	.845-.885

Radiometric Resolution: 16 bit
Orbit: near-polar, sun-synchronous, 705 km in altitude
Swath Width: 2800 km
Data Acquisition:

SeaWiFS Project Code 970.2 NASA Goddard Space Flight Center Greenbelt, MD 20771 Phone (301) 286-9676 Seawifs.gsfc.nasa.gov/SEAWIFS.html	Orbimage 21700 Atlantic Blvd. Dulles, VA 20166 Phone (703) 406-5800 Fax (703) 404-8061 info@orbimage.com www.orbimage.com

Applications: measurement of ocean primary production and phytoplankton.
Source: NASA

Landsat MSS

Probably the most widely-used terrestrial remotely-sensed information is derived from the Landsat series of satellites. The first Landsat was launched in 1972, carrying the Multispectral Scanner (MSS), with a spatial resolution of 79 meters. The images received from this instrument fundamentally altered the way we view the terrestrial environment, allowing for large-scale environmental analysis and vegetation monitoring worldwide.

Vital Statistics
Operator: NASA and Space Imaging Corporation (formerly EOSAT)
Dates of Operation: 7/23/72 to present
Spatial Resolution: 79 meters
Temporal Resolution: Landsat 1 -3: every 18 days, Landsat 4 and 5: every 16 days
Spectral Resolution:

*Band**	4	5	6	7	8 (Landsat 3 only)
Wavelength (mm)	.50 to .60	.60 to .70	.70 to .80	.80 to 1.1	10.4 to 12.6

*Band numbering was changed from 4-7 to 1-4 on Landsats 4 & 5

Radiometric Resolution: 6 bit
Orbit: near polar, sun-synchronous, altitude of 900 km (Landsat 1-3) and 705 km (4 &5)
Swath Width: 185 km
Data acquisition:

Customer Services U.S. Geological Survey EROS Data Center 47914 252nd Street Sioux Falls, SD 57198-0001 Tel: (605) 594-6151 or 1-800-252-GLIS Fax: (605) 594-6589 custserv@edcmail.cr.usgs.gov http://edcwww.cr.usgs.gov/eros-home.html	Space Imaging Corp. (formerly EOSAT) 12076 Grant Street Thornton, Colorado 80241 Phone: (303) 254-2000 or 800-425-2997 Fax: (303) 254-2215 info@spaceimaging.com www.spaceimaging.com Customer Service: 800-232-9037.

Applications: vegetation mapping, geology, regional land cover mapping
Source: NASA

Landsat TM

A decade after the first MSS instrument, Landsat 5 was launched with a new sensor known as Thematic Mapper (TM), with a spatial resolution of 30 meters. Landsat TM was deployed specifically for geologic applications, measuring moisture content in vegetation and soil, and for analyzing surface temperature. The major advantage of the large MSS and TM data archive is the ability to use Landsat data to monitor changes in the landscape over time. The continued importance of Landsat data to the remote sensing community is nearly assured with the recent launch of an Enhanced Thematic Mapper (ETM) aboard Landsat 7.

<u>Vital Statistics</u>
Operator: NASA and Space Imaging Corporation (formerly EOSAT)
Dates of Operation: 7/16/82 to present
Spatial Resolution: 28.5 m (120 m Band 6) Landsat 7 includes 15 m panchromatic.
Temporal Resolution: every 16 days
Spectral Resolution:

Band	1	2	3	4	5	6	7
Wavelength (mm)	.45-.52	.52 -.60	.63 - .69	.76- .90	1.55-1.75	10.40-12.50	2.08-2.35

Radiometric Resolution: 8 bit
Orbit: near polar, sun-synchronous, 705 km in altitude
Swath Width: 170 km
Data acquisition:

Customer Services U.S. Geological Survey EROS Data Center 47914 252nd Street Sioux Falls, SD 57198-0001 Tel: (605) 594-6151 or 1-800-252-GLIS Fax: (605) 594-6589 custserv@edcmail.cr.usgs.gov http://edcwww.cr.usgs.gov/eros-home.html	Space Imaging Corp. (formerly EOSAT) 12076 Grant Street Thornton, Colorado 80241 Phone: (303) 254-2000 or 800-425-2997 Fax: (303) 254-2215 info@spaceimaging.com www.spaceimaging.com

Applications: agriculture and forestry assessment, land use/land cover monitoring, hydrology, shoreline dynamics, mapping, relative surface thermal patterns
Source: NASA

SPOT

The first Systeme Pour l'observation de la Terre (SPOT) satellite, developed by the French Centre National d'Etudes Spatiales (CNES), was launched in early 1986. The second SPOT satellite was launched in 1990 and the third was launched in 1993. The sensors operate in two modes, and provide data in two formats, multispectral and panchromatic.

One element that makes the SPOT scanner unique is its off-nadir viewing capability. Off-nadir refers to any point that is not directly beneath the detectors, but off to an angle. Using this off-nadir capability, one area on the earth can be viewed as often as every 3 days. Off-nadir viewing can be programmed from the ground control station and is quite useful for collecting data in a region not directly in the path of the scanner or in the event of a natural or man-made disaster, where timeliness of data acquisition is crucial. It is also very useful in collecting stereo data from which elevation data can be extracted.

Vital Statistics
Operator: CNES (France)
Dates of Operation: 2/22/86 to present
Spatial Resolution: 10 m panchromatic, 20 m multispectral
Temporal Resolution: every 26 days
Spectral Resolution:

Band	1	2	3
Wavelength (mm)	.5 - .59	.61 - .68	.79 - .89

Radiometric Resolution: 8 bit
Orbit: near polar, sun-synchronous 830 km in altitude
Swath Width: 60 km
Data acquisition: various resellers throughout the U.S. supply SPOT data. A list of these companies can be obtained from:
SPOT Image Corporation
1897 Preston White Drive
Reston, VA 20191-4368
Tel (703) 715-3100
Fax (703) 648-1813
www.spot.com

Applications: mapping, vegetation monitoring, land cover/land use change, coastal resource analysis.
Source: SPOT Image Corporation

CASI

Unlike the satellite systems mentioned above, the Compact Airborne Spectrographic Imager (CASI) is a portable sensor that is flown by numerous private companies on a variety of aircraft. It is a hyperspectral instrument capable of detecting information in up to 288 discrete bands of the spectrum. Each band covers a wavelength range of 0.018 µm. While spatial resolution depends on the altitude of the aircraft, the spectral bands measured and the bandwidths used are all programmable to meet the user's specifications and requirements.

Vital Statistics
Operator: Manufactured by ITRES-Canada, see data acquisition section for details
Operation Dates: 1994 to present
Spatial Resolution: varies with altitude, maximum altitude of 3048 m.
Spectral Resolution: up to 288 bands depending on operating mode with a 545nm spectral range between 400nm and 1000nm
Operating Modes: CASI can be operated in any of the following three modes.

Spatial	Spectral*		Full Frame
512 spatial pixels 19 spectral bands max. 110 frames/s max. (1 band)	288 spectral pixels 101 adjacent Look Directions 13 frames/s max.	48 spectral pixels 511 adjacent Look Directions 13 frames/s max.	512 spatial pixels 288 spectral pixels

*These figures represent a range of alternatives based on the trade-off between the number of look directions and spectral pixels

Radiometric Resolution: 12 bit
Swath Width: will vary with user needs
Data acquisition: ITRES is the manufacturer of the CASI instrument.
There are a number of companies specializing in flight planning, instrumentation, and CASI data processing including Borstad Associates

ITRES Suite 155, East Atrium 2635 - 37 Avenue N.E. Calgary, Alberta CANADA T1Y 5Z6 Tel: (403) 250-9944 Fax: (403) 250-9916	Borstad Associates 114 - 9865 West Saanich Road Sidney, British Columbia, CANADA V8L 5Y8 Tel: (250) 656-5633 Fax: (250) 656-3646 www.borstad.com

Applications : CASI is used for generating information products for forestry, agriculture, water, military, and target identification applications.

Source: ITRES and Borstad Associates

CZCS

The Coastal Zone Color Scanner was launched in 1978 with the goal of monitoring the Earth's oceans and water bodies. Its main objective was to observe ocean color and temperature, particularly in the coastal zone. It was the first instrument with sufficient spatial and spectral resolution to detect pollutants in the upper levels of the ocean and to distinguish suspended materials in the water column. CZCS was eventually replaced by SeaWiFS.

Vital Statistics
Operator: NASA
Dates of Operation: November, 1978 to June, 1986 on board Nimbus-7
Spatial Resolution: 825 m
Temporal Resolution: daily
Spectral Resolution:

Band	1	2	3	4	5	6*
Wavelength (mm)	.43 - .45	.51 - .53	.54 - .56	.66 - .68	.70 - .80	10.5 - 12.50

*not functional beyond 1979

Radiometric Resolution: 8 bit
Orbit: near-polar, sun-synchronous, at an altitude of 955 km
Swath Width: 1566 km
Data Acquisition: The CZCS level 1, 2 and 3 data products are available from the Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC): http://daac.gsfc.nasa.gov

NASA Goddard Space Flight Center
Greenbelt, Maryland 20771
Telephone: (301) 286-9676
http://seawifs.gsfc.nasa.gov/SEAWIFS/IMAGES/CZCS_DATA.html
http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/OB_main.html

Applications: ocean color, pigment concentrations, sediment distribution
Source: NASA

AirSAR

Airborne Synthetic Aperture Radar is flown on a NASA DC-8 jet which can be requested to fly specific missions. The instrument is capable of imaging in three distinct bands of the microwave spectrum.

Vital Statistics
Operator: Jet Propulsion Laboratory (Instrument) and NASA (Aircraft)
Dates of Operation: in current configuration since 1993, first flown in 1988
Operating Modes: POLSAR, XTI (TOPSAR), ATI
These modes describe three configurations of the three bands used on AirSAR. These bands are P, L, and C. Their characteristics are described in the table below.

	P-Band	**L-Band**	**C-Band**
Bandwidth	.68 m	.25 m	.057 m
Frequency	438.75 Mhz	1248.75 Mhz	5298.75 Mhz
Spatial Resolution	~ 12 sq. m		
Slant Range Resolution	10 m		
Azimuth Resolution	1 m		
Geographic Extent	10 – 15 square kilometers		

Data acquisition:
Radar Data Center
Mail Stop 300 - 233
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
Fax: (818) 393 2640
e-mail: radar.data@jpl.nasa.gov
http://airsar.jpl.nasa.gov

Applications: ocean currents, fronts, and other features; coastal zone mapping and monitoring; ship detection; oil spill detection
Source: Jet Propulsion Laboratory

RADARSAT

RADARSAT is a relatively recent spaceborne SAR system, launched on November 4, 1995. RADARSAT is managed by the Canadian Space Agency in cooperation with the Canada Centre for Remote Sensing. It is a highly flexible sensor capable of a variety of imaging configurations (Fig. 7).

Vital Statistics

Operator: Canadian Space Agency (launched by NASA & NOAA)
Dates of Operation: 11/4/95 to present
Modes of Operation: RADARSAT is an extremely versatile instrument with seven modes of operation and multiple beam positions within those modes (Fig. 7).
Temporal Resolution: revisit every 24 days, with 7- and 3-day revisit times possible.
Orbit: near-polar, sun synchronous with an altitude of 798 km
Data Acquisition:

RADARSAT International Inc. 3851 Shell Road, Suite 200 Richmond, British Columbia Canada V6X 2W2 Tel: (604) 244-0400 Fax: (604) 244-0404 www.rsi.ca.	David Hisbal Marketing Manager - Mapping Space Imaging 12076 Grant Street Thornton, CO 80241 Tel: (303) 254-2177 Fax: (303) 254-2215 www.spaceimaging.com

Applications: ocean features; coastal zone mapping; ship detection; oil spill detection

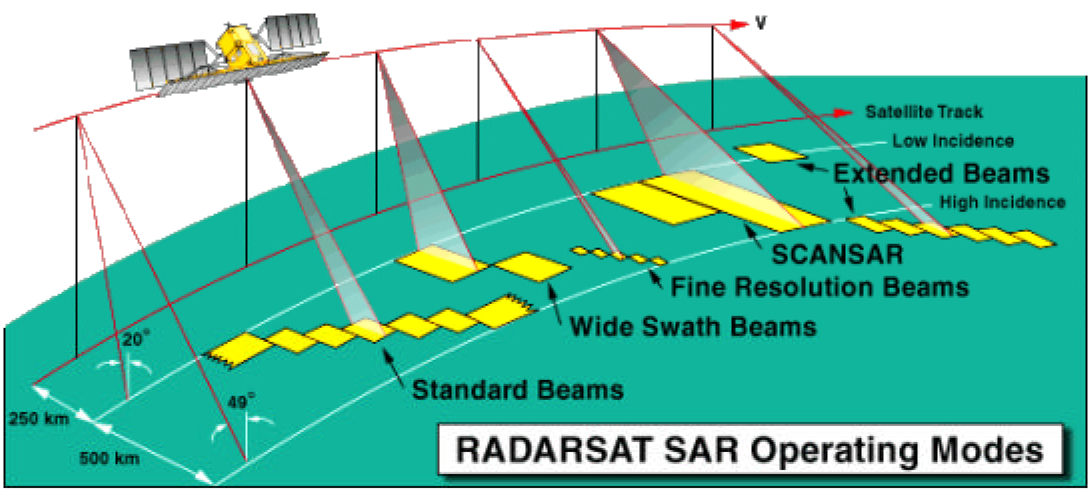


Figure 7 Canada Centre for Remote Sensing

Source: Canada Centre for Remote Sensing